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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

The Rocky Mountain Millivolt Integrator for Use with Solar Radiation Sensors

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Electronic integration of a radiometer's millivolt signal is a practical and accurate means of obtaining hourly, daily, weekly, or long-term radiation values. Our integrator consists of four printed circuit boards, a synchronous bi-directional stepper motor, and 5-decade counter. Each integrator is calibrated to match the millivolt output of the radiation sensor, so that the counter reads directly in langleys. The totalizing of a signal from a typical net radiometer with a 6.20mv/langley output) would be within ±1 percent over most of the positive signal range, but could be 5 percent too low at night when the sensor output is negative.

Keywords: Solar radiation, instrumentation, electronic equipment.

Electronic integration is a practical and accurate means of obtaining radiation values over any time period greater than about a minute. Most often we are interested in daily, monthly, or yearly values. Reducing radiation data from strip charts is time consuming and inaccurate.

The Rocky Mountain millivolt integrator, designed for either a solar pyranometer (fig. 1) or net radiometer, is calibrated to match the millivolt output of the sensor so that it reads directly in langelys.

There are several integrators or totalizers described in the literature. A list of references on the subject is given at the end of this Note. Tanner (1965) did an excellent job of describing the various types of integrators available at that time. Since 1965, advances in integrated circuits have allowed an increase in instrumental accuracy and a decrease in power requirements. The integrator described here is unique in that it employs a bi-directional stepping motor to drive a counter.

Figure 1.--Voltage integrator sums millivolt signal from pyranometer directly in langleys and displays it on a 5-decade counter. It can be read over any time period of interest from 5 minutes to several days.

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Integrators that employ the coulometer, Solion, or other types of electrolytics are probably the most economical, but they are also the least accurate, mainly because of readout difficulties. A major drawback to many of the integrators discussed in the literature is the large DC current drain, or the need for AC current.

The Rocky Mountain integrator combines accuracy, low cost, and low power requirements. The cost of the instrument we built was approximately $150. Current drain averaged slightly over 300 milliamps.

Construction and Principle of Operation

The Rocky Mountain millivolt integrator consists of four printed circuit boards (three when used with a pyranometer), a synchronous bi-directional stepper motor, and a 5-decade counter. A block diagram and an overall schematic of the integrator are given in figure 2. The four printed circuit boards are illustrated schematically in figures 3, 4, and 5, and photographically in figure 6.

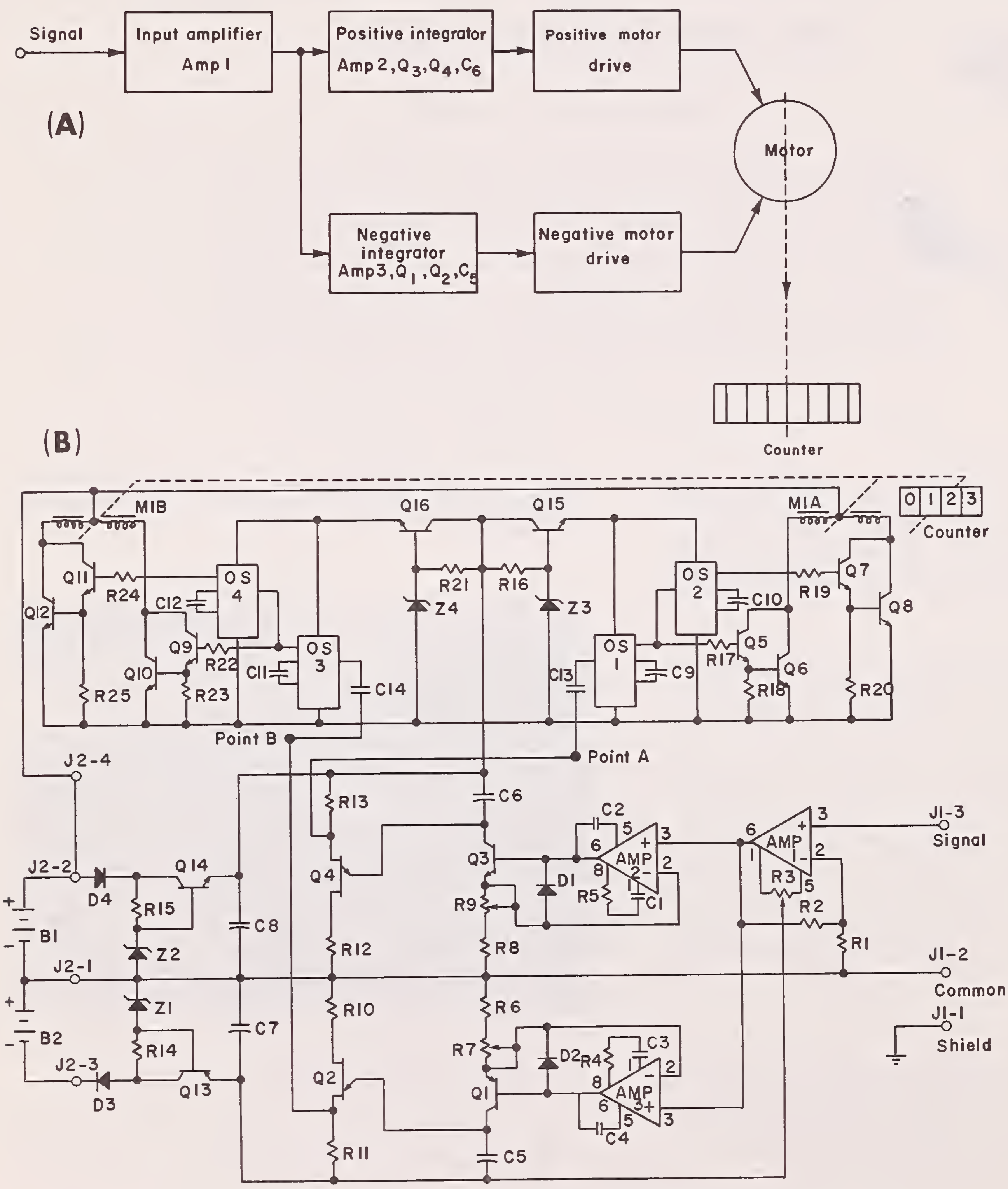


Figure 2.--Rocky Mountain millivolt integrator:

A, block diagram;

B, schematic diagram.

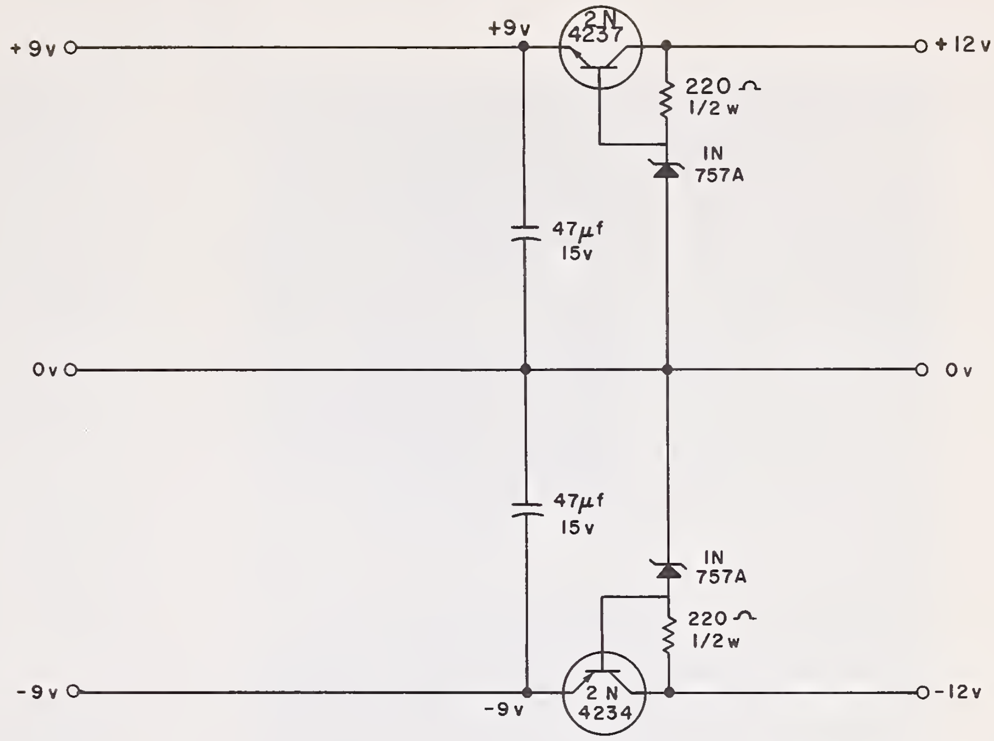


Figure 3.--
Power supply board schematic for Rocky Mountain integrator.

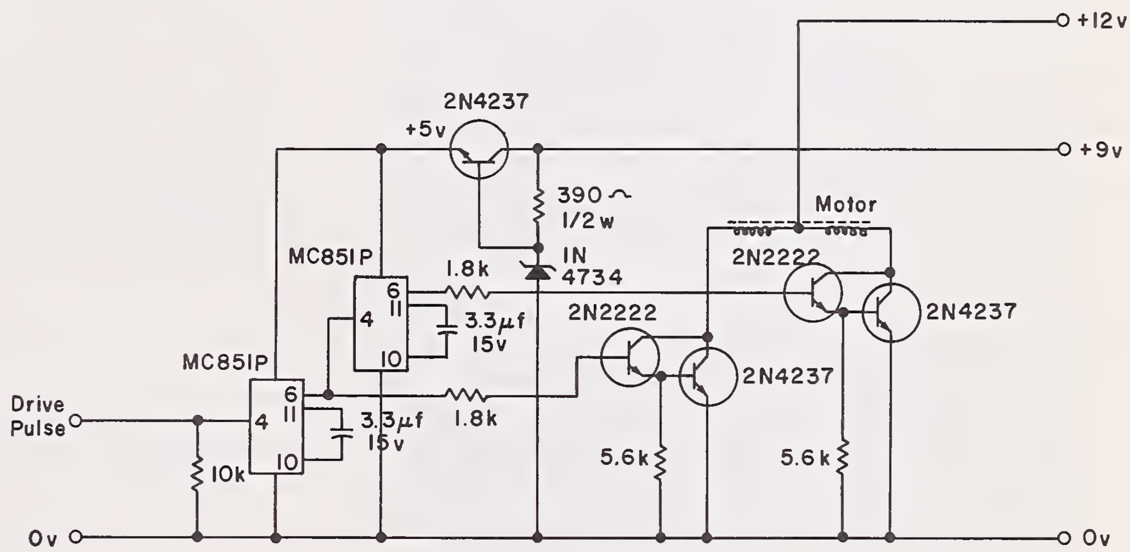


Figure 4.--
Motor driver board schematic for Rocky Mountain integrator. Two required for net radiometer, one for solar pyranometer.

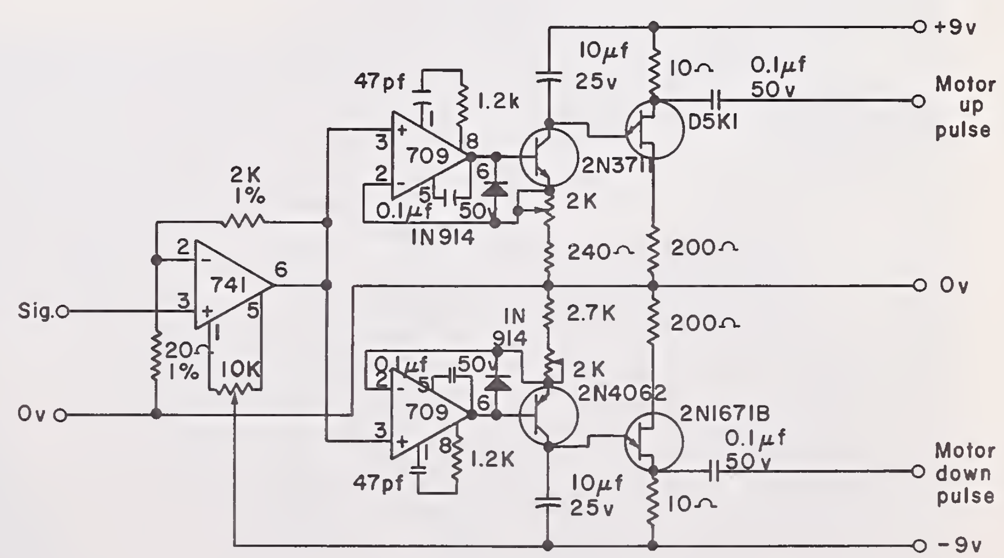
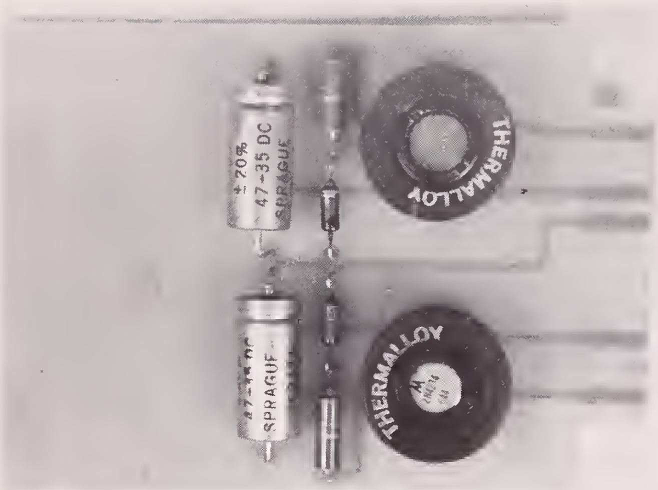
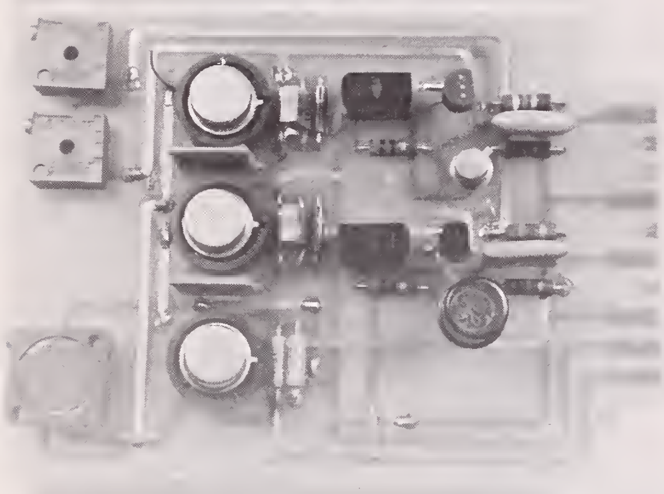


Figure 5.--
Amplifier board schematic for the Rocky Mountain integrator.
NOTE:
+9v and -9v used to supply amplifier modules.

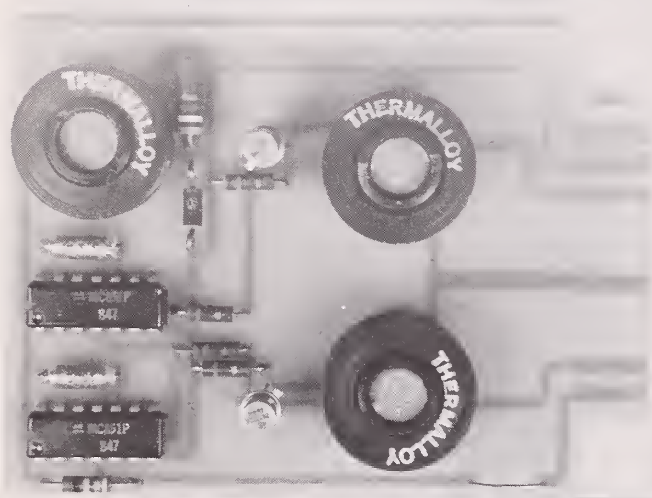
Figure 6.-- The printed circuit board layout used in the Rocky Mountain integrator:



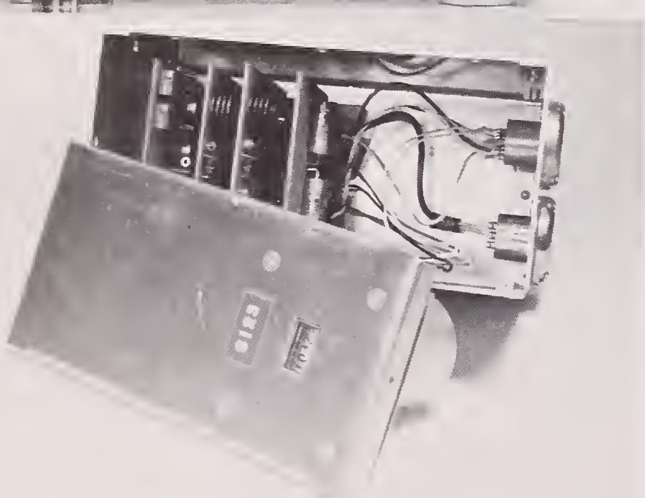
A, power supply;



B, amplifier;



C, motor driver;



D, the completed unit.

The integrator is similar to several other integrators defined as "relaxation oscillators" by Tanner (1965). It is unique in that it uses a bi-directional stepping motor to drive a counter. The stepping motor is driven by pulses from two integrating circuits, one for positive and one for negative input signals. The two integrating circuits are calibrated separately, thus allowing the output of a net radiometer to be totalized.

In figure 2B, the input amplifier, Amp 1, is a low-drift integrated-circuit operational amplifier with internal frequency compensation. It is connected in the non-inverting mode which presents a high input impedance to the input signal. The gain is set at 1000 by the ratio R2/R1. R3 is a balance adjustment used to set the output of Amp 1, with zero signal, to compensate for offsets in Amp 1, Amp 2, and Amp 3.

The positive integrator is composed of Amp 2, Q3, and Q4. Amp 2 and Q3 charge C6 with a current equal to (1000 × Sig)/(R8 + R9). When the voltage across C6 reaches the peak point of the complementary unijunction, Q4, the unijunction conducts and discharges C6. A pulse is fed to the shaping and driving circuits consisting of monostable multivibrators, OS1 and OS2, and associated transistors. The negative integrator consists of Amp 3, Q1, and Q2, which drive OS3 and OS4 and their transistors.

Calibration

An accurate voltage divider was developed to insure proper calibration of the voltage integrator for a given radiometer. This allows long-term calibration checks with constant (±0.0025 percent) millivolt inputs within the range of the output level from a radiation sensor.

The bench setup used in calibrating the integrator is shown in figure 7. The voltage divider is used to simulate the output from the radiometer that will be used with a particular integrator. A precision millivolt potentiometer is necessary to adjust the output from the divider to the desired levels that will make the integrator read directly in langleys.

Because the integrator output is linear with respect to input, only one point of each polarity of input is necessary for calibration. This point was arbitrarily chosen to represent 1.0 langley.

When the input voltage is set at the level representing 1.0 langley, the time interval between pulses from the integrating circuits (Point A for positive input, Point B for negative, fig. 2B) is set with R9 and R7, respectively. The time interval should be 100 milliseconds at 1.0 langley and 400 milliseconds when checked at 0.25 langley. Using a frequency counter with period averaging, the period can be set to 1/2 percent on the high level with 2 percent accuracy on the low level.

Long-term precision of the integrator was tested by supplying a constant input voltage from the divider over a period of 5 days. The error in voltage integration was only -0.9 percent on the negative input side and ± 0.6 percent on the positive input side.

Calibration tests under temperature conditions ranging from 75° to 108°F are presented in figure 8. Because wet-cell batteries are required

Figure 7.--To accurately calibrate the voltage integrator for a given radiometer, an accurate voltage divider was developed by the Rocky Mountain Station. This allows long-term calibration checks with constant (± 0.0025 percent) milivolt inputs that simulate the output from a radiation sensor.

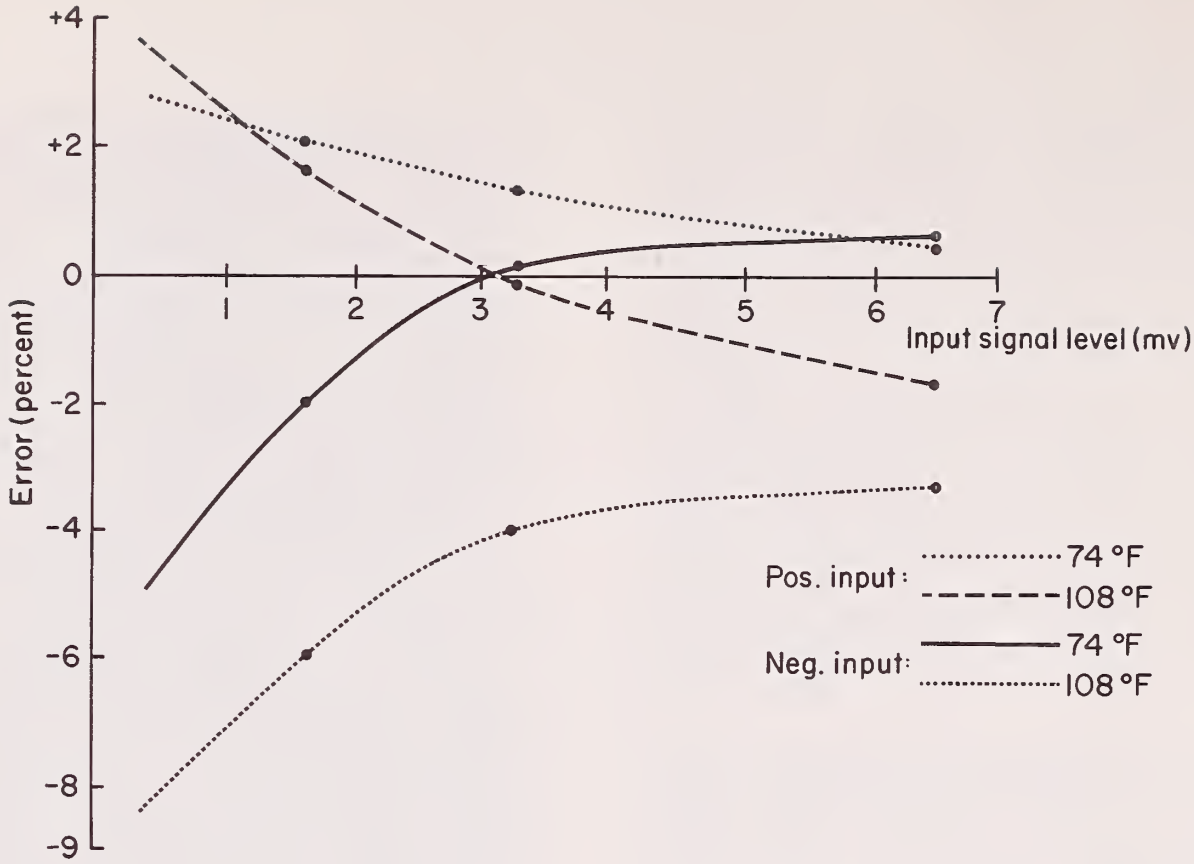


Figure 8.--Variations in the calibration of the RM millivolt integrator with temperature and signal level.

for a power source, a heated shelter is required when freezing temperatures are encountered. Maintaining a shelter environment of 75° to 100° F would minimize the integrator errors caused by temperature drift. Negative net radiation amounts to only 10 to 20 percent of the daily total, therefore a 5 to 6 percent nighttime integrator error is comparable to a 1 to 2 percent daytime error. If nighttime values are of interest by themselves, the shelter temperature becomes more critical in order to minimize the negative integrator error.

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Parts List[2]

B1 Battery, 12v lead-acid

B2 Battery, 12v lead-acid

C1 Capacitor 47pf

C2 Capacitor 0.1µf

C3 Capacitor 47pf

C4 Capacitor 0.1µf

C5 Capacitor 10µf, 15v

C6 Capacitor 10µf, 15v

C7 Capacitor 47µf, 15v

C8 Capacitor 47µf, 15v

C9 Capacitor 3.3µf, 15v

C10 Capacitor 3.3µf, 15v

C11 Capacitor 3.3µf, 15v

C12 Capacitor 3.3µf, 15v

C13 Capacitor 0.1µf

C14 Capacitor 0.1µf

D1 Diode 1N914

D2 Diode 1N914

D3 Diode 1N4005

D4 Diode 1N4005

J1 Jack 91-855 (Amphenol)(Mates 91-854)

J2 Jack 91-859 (Amphenol)(Mates 91-858)

M1 Stepping motor K-44135-P2;
50:1 gear reduction (A. W. Haydon)

Counter A1141 25-005 (Veeder-Root)

Edge connectors 251-20A-30 (Cinch-Jones)

Q1 Transistor 2N4062

Q2 Transistor 2N3711

Q3 Transistor 2N3711

Q4 Transistor D5K1 (G.E.)

Q5 Transistor 2N2222A

Q6 Transistor 2N4327

Q7 Transistor 2N2222A

Q8 Transistor 2N4237

Q9 Transistor 2N2222A

Q10 Transistor 2N4237

Q11 Transistor 2N2222A

Q12 Transistor 2N4237

Q13 Transistor 2N4234

Q14 Transistor 2N4237

Q15 Transistor 2N4237

Q16 Transistor 2N4237

Unless otherwise stated,
all resistors are ± 5%, 1/4W

R1 Resistor 20Ω, ± 1%, 1/4W

R2 Resistor 2KΩ, ± 1%, 1/4W

R3 Variable resistor 10K, Pot.;
Bourns #3280P-1-103

R4 Resistor 1.2KΩ

R5 Resistor 1.2KΩ

R6 Resistor 2.7Ω (Selected for proper
range of calibration adjustment)

R7 Variable resistor 2.7Ω, Pot.;
Bourns #3280P-1-202

R8 Resistor 240Ω (Selected for proper
range of calibration adjustment)

R9 Variable resistor 2KΩ, Pot.;
Bourns #3280P-1-202

R10 Resistor 200Ω

[2] *The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.*

R11 Resistor 10Ω

R12 Resistor 200Ω

R13 Resistor 10Ω

R14 Resistor 220Ω, ± 5%, 1/2W

R15 Resistor 220Ω, ± 5%, 1/2W

R16 Resistor 390Ω, ± 5%, 1/2W

R17 Resistor 1.8KΩ

R18 Resistor 5.6KΩ

R19 Resistor 1.8KΩ

R20 Resistor 5.6KΩ

R21 Resistor 390Ω, ± 5%, 1/2W

R22 Resistor 1.8KΩ

R23 Resistor 5.6KΩ

R24 Resistor 1.8KΩ

R25 Resistor 5.6KΩ

Z1 Zener diode 1N4739A

Z2 Zener diode 1N4739A

Z3 Zener diode 1N4734A

Z4 Zener diode 1N4734A

Amp 1 Operational amplifier U5B7741312 (Fairchild)

Amp 2 Operational amplifier U5B770931X (Fairchild)

Amp 3 Operational amplifier U5B770931X (Fairchild)

OS1 Monostable multivibrator MC851P (Motorola)

OS2 Monostable multivibrator MC851P (Motorola)

OS3 Monostable multivibrator MC851P (Motorola)

OS4 Monostable multivibrator MC851P (Motorola)